Update for Experiment E1039
December 2014

Joint E906/E1039 statement

The collaboration has agreed on the following plan as the best path forward in terms of physics and timeliness. While the beam intensity for E906 is lower than requested, we feel that E906 will, by summer 2016, accumulate enough statistics to substantially achieve its physics goals. At this point, we propose to start the changeover to the E1039 configuration by installing the polarized target. We estimate that this installation will take roughly 6 month at which time the commissioning of E1039 will start. After this period, we are planning to run for two years with a polarized proton target.

Optimizing the Experiment and new Estimates based on E906

Since the presentation to the PAC in July 2013, three significant improvements to the experiments performance have been achieved:

- *The spectrometer acceptance for low Bjorken x has been improved by a factor of 2.*
- *The event reconstruction efficiency has been improved by a factor of 6.*
- *The accelerator has achieved a 50% increase in the number of "useful" protons.*
- *In spite of a reduced integrated luminosity these improvements result in an increase of 3.3 in statistics..*

The combination of these improvements results in a dramatic increase in the statistic.

We have modified the original E906 Monte Carlo and included a realistic simulation of the 5T target magnet. Because of the requirement that the field homogeneity of the target magnet is better than $dB/B < 10^{-4}$,we checked the fringe field of FMAG at the current target position. The field variation turned out to be of the order of 25G , which can be easily handled by field clamps. However, in the analysis of E906 it turned out that because of the limited vertex resolution along the beam axis, a cut to the data had to be applied, in order to clearly separate events from the dump from the ones from the target. This cut reduced the reconstruction efficiency by ~25 **%.**In order to eliminate this data loss we studied moving the target upstream by 220 cm to -350cm from the front of FMAG. Our calculations show that this leads to a significant increase in the x_T acceptance of the spectrometer as shown in figure 1.

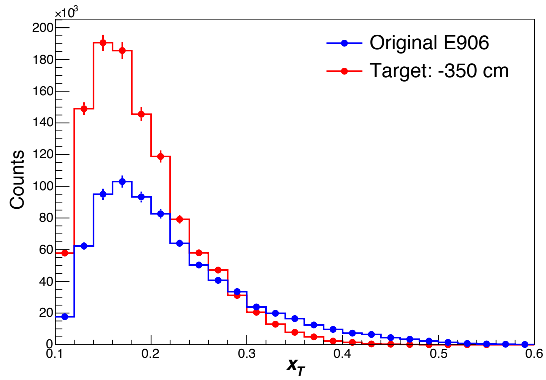


Figure 1: Accepted events for polarized target in the E906 target position (blue) and the new position (red).

At the lowest two xbins, this leads to an increase of roughly a factor of two. While such a repositioning of the target increases the background at the edges of the spectrometer, only a small increase occurs in the region of high mass DY pairs. Our study of the trigger efficiency has shown that we can run the experiment the E906 trigger rate, but with higher efficiency, because the background roads in the trigger matrix are more localized at the edge of the acceptance.

In addition to the optimizing studies, the reconstruction team of E906 has also made tremendous progress, improving the reconstruction efficiency for di-muon events. Compared to our original LOI this reconstruction efficiency has improved by factor of 6.

For our original calculations we used the beam intensity assumption of the original E906 proposal which assumed a 60% duty factor, since at this time this was still considered a realistic assumption. the experience over the last year have shown that this number was too high and the accelerator was only able to provide up to 30% DF, limiting the number of protons collected and also leading to higher DAQ dead time. However, in the 3rd week of December a dramatic increase of the duty factor has been achieved as shown in figure

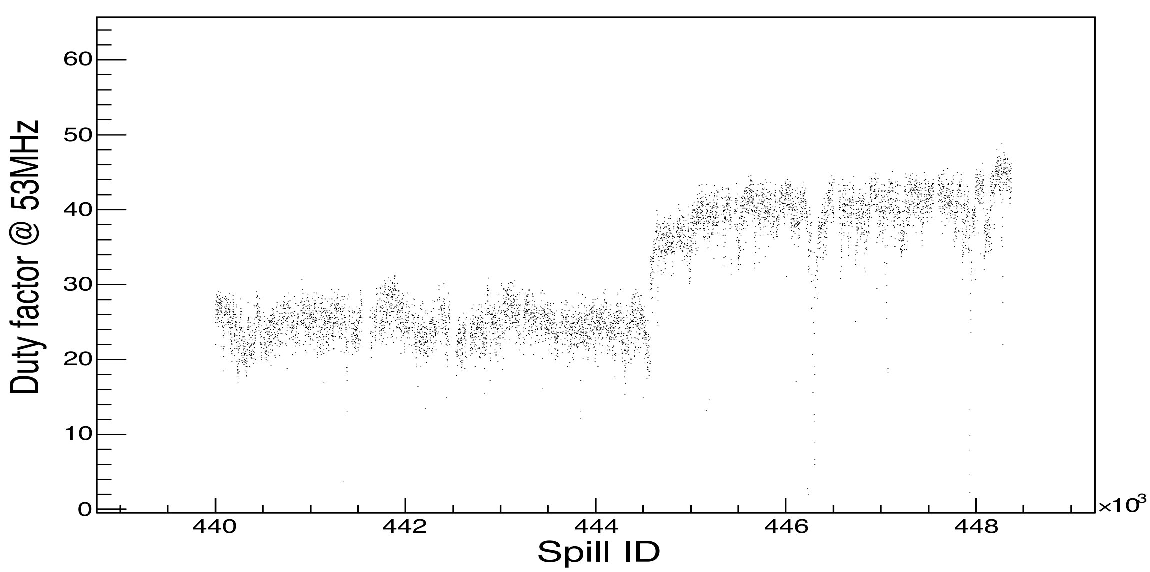
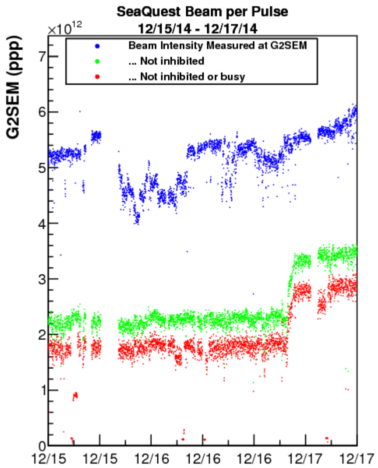


Figure 2: The change in duty factor as seen on Dec 16. The x-axis displays the spill number, which corresponds to time.



The duty factor increased from slightly below 30% to 40% and is still showing an increasing trend. This immediately translates in an overall increase of the useful protons of 50% as can be seen in figure. The red curve represents the “good” protons, where neither an inhibit due to poor beam quality was nor was the DAQ busy.

Figure 3 A strip chart of the proton intensity.

In the following table we show the projected statistical errors for the four data bins. These improvements will allow us to bin the data in four bins instead of the original three. One can clearly see the improvement in the error by moving the target backwards from the current E906 target position.

x_T Bin	Mean x_T	N: E906	N: -350 cm	ΔA: E906	ΔA: -350 cm
0.10 - 0.14	0.126	18735	68390	5.2	2.7
0.14 – 0.17	0.155	34811	93806	3.8	2.3
0.17 – 0.21	0.188	43819	100403	3.4	2.2
0.21 – 0.50	0.259	78121	106423	2.5	2.2

Target System Status

Since the presentation of the LOI to the PAC in July 2013, tremendous progress has been achieved with the polarized target.

- *The Superconducting magnet has been reconfigured for transverse polarization.*
- *Designed and purchased the pumping package necessary to reach 1K operation.*
- *We purchased a new 140GHz microwave system.*
- *Designed, built and tested completely new NMR system to measure the polarization.*

Originally, the superconducting magnet was configured for longitudinal polarization, requiring a field parallel with the beam axis. In order to measure the Sivers asymmetry, a transvers nucleon polarization is required, necessitating reorienting the magnet’s split coils by a rotation of 90 degrees. After having successfully tested the magnet at the University of Virginia, we shipped the system to Oxford Instruments (OI, the original manufacturer) in the UK for the necessary changes. Once the magnet had arrived, a path forward was laid out for

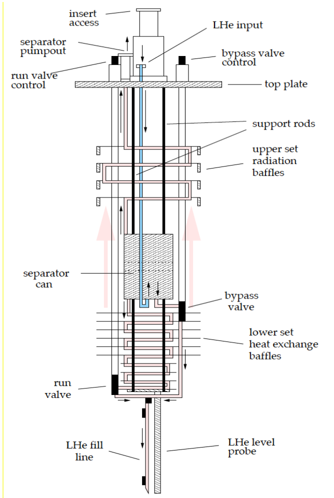
changing the coil assembly, refurbishing the cryogenic plumbing and electronics lines, and a redesign of the lower target part together with a new tail piece for the refrigerator. Because of the transport failure, we also decided to redesign the coil mounting and came up with a design where the coils could be separated from the tanks for shipping.
In Spring of 2014, OI started with the refurbishing and reorienting work, which they finished at the end of November 2014. Subsequently, the magnet system has been completely assembled and undergone leak checking at 70K. We will travel to Oxford in the last week of January for two weeks of acceptance testing and shipping preparation of the system. We anticipate to have the magnet fully operational in the US in spring 2015. (120K$)

During this time, we have designed a pump package necessary to cool the target system to the low operating temperature necessary. As described above, the polarized target operates at 1K and a field of 5T. This temperature is reached by lowering the vapor pressure of the liquid Helium bath to .117 Torr . This pumping package will pump roughly 12,000 m^3/hr of Helium gas at STP. We have received the whole system in November 2014, and are in the process of testing it. (190K$)

In order to polarize NH_3, the NH3 material has to be irradiated by 140 GHz microwave. A specialized high power microwave tube, manufactured by CPII, achieves this. While Los Alamos had an old tube, subsequent tests showed that only 50% of the necessary power could be achieved. Sending the tube back to the manufacturer confirmed our initial measurements, and reconditioning efforts at the factory were not successful. We have ordered a new tube in FY14, which was delivered to LANL in the fall. (120 K$)

In order to drive such a tube, a special power supply has to be used, which is built on order. We have purchased such a power supply, and the manufacturer is currently building it. The power supply will be specially tuned at the factory to the tube and then be shipped to Los Alamos in June 2015. (98 K$)

Over the last 30 years the way to measure the polarization was through NMR with the so called Liverpool Q meter. This system was designed in the 70's and relied on now obsolete analog electronic circuitry. In addition, to reach the necessary temperature stability, which is crucial for the Thermal Equilibrium (TE) measurements, the system had to be cooled, leading to a somewhat complicated and cumbersome system. In the case of the typical polarized target of this kind, this was not a problem since one target cell had just one NMR circuit. However, due to the extended size of our target cell (8cm long) we will need to have three circuits for every cell, and each target insert will have two active cells. This requires 6 circuits per target stick, making the Liverpool system unsuitable. We therefor designed a new system with new, state of the art analog and digital components. The first prototype was tested at the UVa polarized target Lab in Spring of 2014, and performed excellently. We showed that the system was extremely low noise and temperature stable. This low noise system will greatly reduce the time needed to measure the TE , the crucial baseline measurement and therefore increase the time we can take beam.
Currently we are modifying the system such that we will have a VME form factor allowing us to have the 6 measurement systems in one VME crate. The boards have already be designed and we plan to test the first prototypes in spring of 2015. (50 K$)



The central part of the whole system are the so called refrigerator and the target insert. The original refrigerator is currently being refurbished by UVa under a contract to the University. While most of the system can be reused, some leaks have been found, which are being worked on. We estimate that the refrigerator work will be finished in summer 15.

Figure 4: A schematic of the refrigerator

We have also started on the design for the target insert for the system. In the current conceptual design, the polarized target cells will have an elliptical face of H:18mm x V:27mm by 80mm long. This is necessitated by the requirements that the geometry of the existing system does not allow for a more extended or circular target. This limited horizontal extension also will require additional optics in the beam line to reduce the size horizontally. Shown is a typical target configuration as used at JLAB. The microwave horns can be easily seen. Because of our extended target (the ones shown are only 2o mm thick) we need different microwave horns. We have already accomplished a new design for the horns and received quotes. Most of the target work is being performed by UVa. In addition, the target stick will have an empty cell and a hole. The system is designed such that we could also load ND_3 thus allowing us to measure DY on a polarized neutron. This would be especially interesting if FNAL would eventually provide polarized beam. The overall size of the UVa contract is 230K$.

Figure 5 A typical target assembly as used at Jefferson Lab. The microwave horns are clearly visible.

In the following we list a table of the purchases made by LANL and the planned costs with the year of purchase.

Purchases	Costs	Delivery
ROOT pumps	$180,000	**FY14**
Microwave tube	$120,000	**FY14**
Microwave power supply	$98,000	FY14/15
NMR system (Prototype)	$15,000	**FY14**
NMR system VME	$20,000	FY15
Chiller, Separator pumps	$70,000	**FY14**
UVa contract part 1	$50,000	**FY14**
UVa contract part 2	$180,000	FY15-16
NIST irradiation	$62,000	FY15-16
Microwave electronics	$50,000	**FY14**
NIST irradiation	$60,000	FY15-16
Travel	$90,000	FY14-16
M&S	$90,000	FY14-16
Contribution to FNAL Infrastructure	$200,000	FY16
TOTAL LANL	**$1,285,000**	**FY14-16**

Estimates of Installation and Infrastructure Needs.

In the following paragraph we will discuss the changes and additions to the base E906 configuration needed, in order to field the polarized target. We have identified four major areas, where substantial work is needed:

- *Cryogenics for liquid Helium and Nitrogen distribution and exhaust*
- *Mechanical layout and modification of the target area*
- *Beamline improvments for a tighter final focus*
- *Shielding modification required for new target location and servces*

Cryogenics:

The major cryogenic issues with a polarized ^{4}He target are the liquid He consumption and the collection of the exhaust gas. Keeping the target at 1K will lead to a overall consumption of roughly 100 liters of liquid He per day. This is a sizable amount of a nonrenewable resource, as well as a large cost. Furthermore, such a system will need a special plumbing and recovery infrastructure consisting of Helium and Nitrogen transferlines, pumping lines from the target to the ROOTS pumps as well as a special quenchline, which would handle the Helium exhaust gas in case of a magnet quench. Together with the FNAL cryogenic group we have developed three different scenarios for the liquid Helium and obtained quotes and cost estimates for each of them:

1. A closed loop system
2. A system where we buy liquid helium and collect the exhaust gas.
3. Buy liquid He and exhaust it into the atmosphere

1. *Closed Loop System*
While this would be the preferred way to go in terms of independence from price fluctuation as well as He supply shortages, it turned out to be economically not viable. The total cost of such a system would be close to 2.5M$. The costs of running such a system during the experiment would be relatively small requiring about 10% of a tech FTE

2. *Collecting the exhaust gas.*
Due to space constraints, such a system would have to be in the upper part of the experimental area, requiring extensive cryo-engineering design work, storage facilties for the gas and a compressor, which could transfer the gas from the atmospheric storage area to the helium trailers. The total estimate for this system would be 880K$. A further disadvantage of this solution would be the need for sizable manpower to operate the compressor and transfer the He on a regular basis from one of the storage containers to the He trailers. The estimate for this manpower would be 160K$ a year. In this scenario we need to buy Helium and we have estimated the costs of 1 lt at 10$ (current price is $6.5). Assuming that we would need to run the target at 1K for 250 days of beam, we estimate the yearly total costs of running the polarized target to be 406K$.

3. *Venting the Helium into the atmosphere*
While this solution still requires the same transferlines as the other two proposals, we would not need additional storage space or a compressor. Our cost estimate for this approach comes out to 613K$ and the yearly costs would be the costs of the liquid Helium, which would be 250K$

While venting the Helium is certainly an undesirable approach, it seems to be the only financially viable solution without additional significant investment from either DOE or FNAL.

Mechanical Issues

As we have outlined in the section describing the progress in optimizing the experiment, we will need to move the target 220 cm upstream from it's current position as indicated in the displayed figure. However this configuration poses not only challenges in terms of routing all the necessary cryogenics and pump lines but also in terms of mechanical and new shielding issues. This position will require some restacking of the shielding immediately above the magnet in order to have enough vertical space to change the target , which we will need to do roughly every 10 days, in order to exchange the radiation damage material. In addition we will need a target platform which will allow us to work around the target at a height of 8 feet

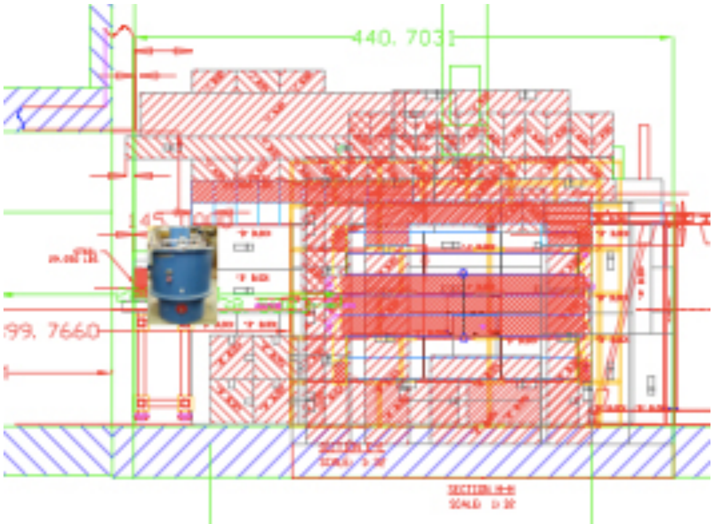


Figure 6 Current Shielding configuration with the polarized target shown in its anticipated position.

(beam height above the ground). A further complication arises from the limited reach of the overhead crane. While we can lower the target into the area on the side, the crane will not be able to access the position of the target itself. Therefore we will need to mount a hoist to the overhead shielding. All these mechanical changes to accommodate the target are estimated to be 180K$.

Beamline

Due to the small size of the target and the requirements on the relative luminosities, we will need a beam size of σ_H =2mm and σ_V =3.3mm, which is much smaller than the current E906 beam, which is σ_H =4mm and σ_V =3mm. This will require additional quadrupole magnets. We will also need a collimator upstream of the target , which will prevent possibility of the beam hitting the polarized target coils and quenching it due to miss-steering. At the time of this update writing, the estimates were still being done.

Overall Table of costs as currently known with the three different cryogenics options.

Installation			
	Closed Loop	Balloon Storage	exhaust
	$2,455,308	$892,280	$613,280
-LANL contribution	- $240,000	- $240,000	- $240,000
Cryo Installation	**$2,215,308**	**$652,280**	**$373,280**
Target Mechanical	$180,000	$180,000	$180,000
Electrical	$54,000	$54,000	$54000
Beamline			
Shielding			
Total as of 12/21/14	**2,449,308**	**$886280**	**$607,280**
Yearly running costs:			
Cryo	$156,000	$406,000	$250,000
E906 (70% contingency)	$61,200	$61,200	$61,200
TOTAL yearly	**$217,200**	**$467,200**	**$311,200**

The mechanical and electrical calculations have an overall contingency of **50%** and the cryogenic estimate one of **60%**.

Shielding Calculations and modifications.

At the current time this cost is the largest uncertainty due to the complexity of the MARS calculations. In order to get an estimate of any additional shielding needed as well as mechanical load calculations and possible civil engineering needed, FNAL has to perform a detailed MARS calculation. We would like to ask FNAL management to provide the necessary resources to the Accelerator division to perform these calculations as soon as possible, such that we could obtain a final cost estimate by the summer of this year.

Collaboration and Contributions from Members

In summer 2014 we had the first collaboration meeting with a session specially dedicated to the E906 extension with a polarized target. At this time, UVa and New Hampshire joined the existing E906 collaboration. In the second week of February we will have our next combined collaboration meeting, where we will discuss possible contributions to the experiment from our collaborators.

The three most critical components of the polarized target are the ROOTS pump system, the microwave tube and its power supply. While the pumps are known to be very stable and run for many years without problems, the tube and power supply are known to fail and in need of repair. It is therefore crucial to run such an experiment with spares for either component on hand. We are glad to report that the University of Michigan will contribute its microwave tube to the experiment, while the University of Virginia has agreed to provide us with a spare power supply. UVa has also assumed the responsibility for the new target inserts and the repair of the refrigerator.

Conclusions

During the last one and a half year we have made large progress in our preparation for a polarized Drell Yan experiment. We have successfully optimized the experimental setup and improved the data reconstruction. Together with an improved duty factor for the beam, these changes lead to an overall improvement of the statistics of 3.3 .

Furthermore, the construction of the polarized target is well under way, most of the major purchases have been done, and the project completion date is still ahead of the E906 end, which will allow us to seamlessly transition from the Seaquest liquid targets to the polarized target. A smooth continuous running of Seaquest will accelerate this process.

We have identified the challenges to the changeover and gotten budget estimates for all but the shielding and beam line modifications. In order to complete these estimates, we are asking for the support from the PAC and FNAL.